

2. SIGNAL CHARACTERISTICS

The purpose of this section is to describe Public Safety LMR and UWB signal characteristics in order to identify potential interference scenarios and rationalize measurement procedures.

2.1 Public Safety LMR Systems

Public Safety LMR systems operate in various bands from about 30 MHz to 900 MHz, with bandwidths currently 25-30 kHz; new regulations, however, require the bandwidths to be reduced to 12.5 kHz (and potentially to 6.25 kHz). Both digital and analog modulation schemes are currently utilized for Public Safety LMR communications. For these measurements, two types of modulation standards were used – Project 25[†] digital signals and traditional analog signals. The Project 25 radios used in these measurements have a 4-level frequency shift keyed (C4FM) modulation confined to 12.5-kHz bands. Two-bit symbols are represented by 4 different frequency shifts, each separated by 1.2 kHz. The analog radio-configuration used for these measurements has a 12.5-kHz bandwidth and employs a frequency modulation (FM).

2.2 UWB Signals

The UWB signal is, in general, a sequence of narrow pulses with widths on the order of 0.2 to 10 ns. Uniform pulse spacing (UPS), as the name implies, means the UWB signal has no modulation and the pulses are spaced equally apart. Modulation of the pulses can take on many different forms. One form of digital modulation is pulse-position modulation where, for example, a pulse that is slightly advanced from its nominal position represents a “zero.” Likewise, a slightly retarded pulse represents a “one.” Another form of digital modulation is on-off keying (OOK) where pulses, in what is normally an evenly spaced sequence, are deleted, thus representing “zeros.” In addition to the modulation scheme, the pulses can be dithered, where pulses are randomly located relative to their nominal, periodic location – absolute referenced dithering (ARD), or relative to the previous pulse – relative referenced dithering (RRD). The extent of dither is expressed in terms of the percentage of pulse repetition period, which is the reciprocal of pulse repetition frequency (PRF). For example, 50% absolute referenced dithering describes a situation where the pulse is randomly located

[†]Project 25 (P25) is a standard developed for Public Safety LMR radio systems to provide digital, narrowband radios with the best performance possible and to permit maximum interoperability. These standards are a joint effort of U.S. Federal, state, and local governments, with support from the U.S. Telecommunications Industry Association (TIA). State Government is represented by the National Association of State Telecommunications Directors (NASTD) and local government by the Association of Public-safety Communications Officials, International (APCO).

in the first half of the period following the nominal pulse location. Finally, some UWB systems employ gating. This is a process whereby the pulse train is turned on for some time and off for the remainder of a gating period.

Four different pulse spacing modes (UPS, OOK, ARD, and RRD) are illustrated in Figure 2.1, whereby the vertical dashed lines represent the ticks of a clock. Gating is represented by the removal of the pulses in the shaded areas; in the case of the UPS example, there are 4 pulses generated during the gated-on time followed by 8 clock ticks for which there are no pulses (to give a duty cycle of 33%).

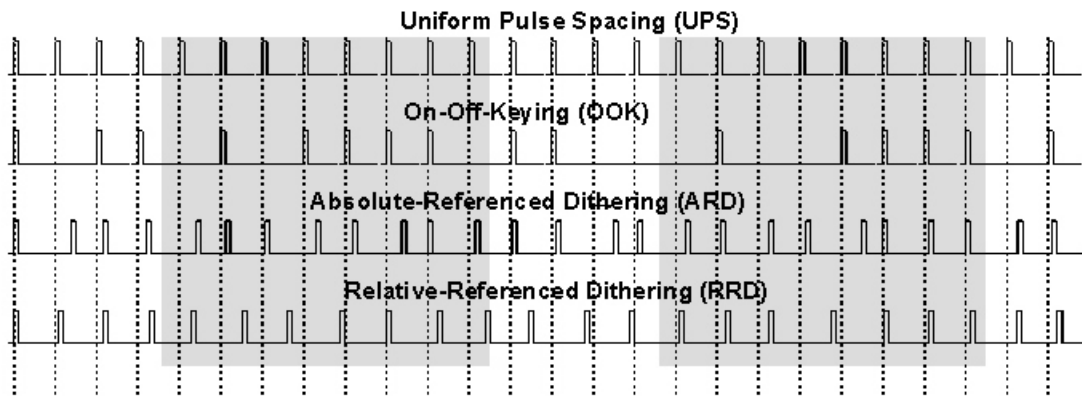


Figure 2.1. Pulse spacing modes.

Spectral Considerations

The frequency domain characteristics (emission spectrum) of a UWB signal are dependent upon the time-domain characteristics described above. The pulse shape/width determines the overall spectral envelope, where the bandwidth is approximately equal to the reciprocal of the pulse width. The manner in which the pulses are sequentially spaced determines the fine spectral features within the confines of the envelope.

Spectral plots are shown in Figure 2.2 for four different UWB signals as they are passed through a bandpass filter.[†] UPS has the power gathered up into spectral lines at intervals of the PRF. The greater the PRF, the wider the line spacing, and the greater the power contained in each spectral line. OOK also has spectral lines spaced at intervals of the PRF that are superimposed on a continuous noise-like spectrum. Dithered signals have spectral characteristics inherently different from either UPS or OOK. For these measurements, ARD has a pulse spacing that is varied by 50% of the referenced clock period. RRD has a pulse

[†]While Figure 2.2 shows spectral plots at a center frequency of 1575 MHz, the principles presented herein apply, as well, to the 138-MHz band of interest.

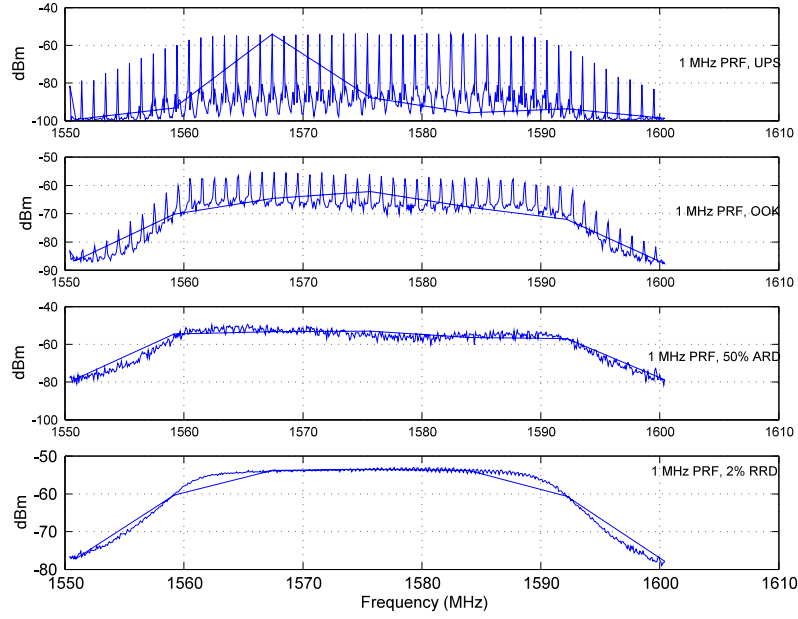


Figure 2.2. Spectral characteristics of the different pulse spacing modes.

spacing that is varied by 2% of the average pulse period. Both of these dithered cases have spectral features that are characteristic of noise (i.e., no spectral lines). The reader is referred to references [2] and [3] for a more in-depth discussion of the spectral characteristics of UWB signals.

Another feature worth noting is the phenomenon of spectral lines spreading due to gating. The spectrum of the gated UWB signal is the result of convolving the non-gated signal with that of a rectangular function, the latter of whose Fourier transform amplitude has a sinc-squared envelope characteristic. It follows that the single line of the non-gated cases is spread out into a multitude of lines confined by the sinc-squared envelope, where the spacing between lines, or line spread spacing (LSS), is equal to the reciprocal of the gating period; null spacing, or line spreading null-to-null bandwidth (LSNB), of the main lobe of the sinc-squared function is equal to two times the reciprocal of gated-on time.

There are two additional spectral features that occur as a result of the signals having been generated by an arbitrary waveform generator (AWG). One is related to how the pattern of pulses is repeated, and the other has to do with the process of placing the pulses into bins, representing discrete dithered pulse spacing. Further discussion of these spectral characteristics of UWB signals is contained in the appendix.

Temporal Characteristics

When a narrow pulse, with a wide bandwidth (BW), is passed through a filter with a narrower bandwidth, the output is essentially equal to the impulse response of the filter; the resultant output has a pulse width approximately equal to the reciprocal of the receiver bandwidth and oscillates at the center frequency of the filter. Figure 2.3 illustrates 50%-ARD signals, at three different PRFs, passed through a 20-MHz bandpass filter (downconverted to an intermediate frequency); the appearance is that of a sinusoid turned on for intervals of 50 ns. The result is that, as the pulse passes through the filter, it becomes wider, the peak-to-average power ratio decreases, and depending upon the PRF and extent of dithering, the pulses may overlap. Because the phase of the oscillation is dependent upon the time origin of the pulse, the phase for adjacent dithered pulses can be asynchronous. This can result in constructive and destructive summation of signal components for overlapping pulses, giving the appearance of random, noise-like signals. OOK signals, while synchronous in phase for adjacent pulses, can have a similar noise-like appearance when adjacent pulses overlap.

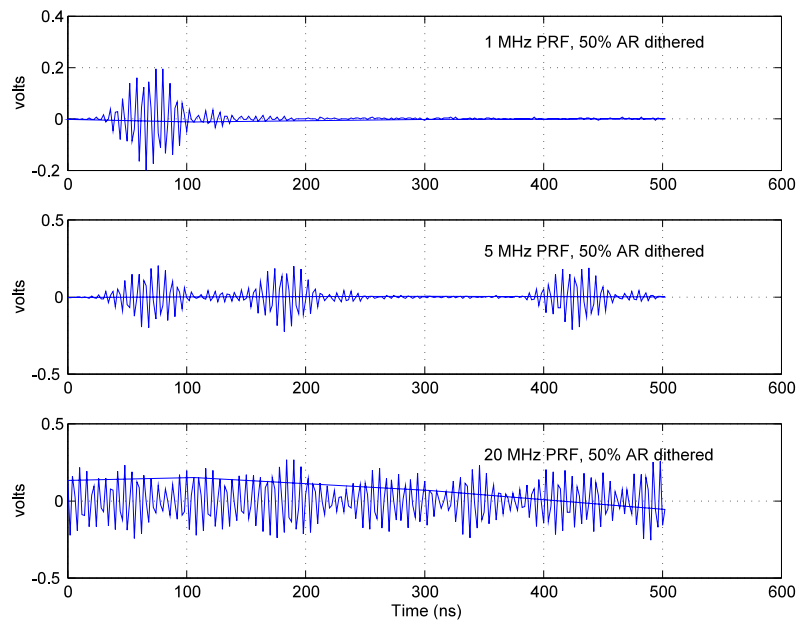


Figure 2.3. Temporal plots of 50%-ARD UWB signals passed through a 20-MHz bandpass filter and downconverted to an intermediate frequency.